UNCLASSIFIED

AD NUMBER
AD912508
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Administrative/Operational Use; FEB 1973. Other requests shall be referred to Air Force Armament Lab., Eglin AFB, FL 32542.**
AUTHORITY
AFTAL ltr 17 Oct 1975

THIS PAGE IS UNCLASSIFIED

AD 912508

AFATL-TR-73-40

DEVELOPMENT OF A MINIATURE ALL-SECONDARY-EXPLOSIVE, LOW-VOLTAGE, ELECTRIC DETONATOR

SYSTEMS, SCIENCE AND SOFTWARE

TECHNICAL REPORT AFATL-TR-73-40

FEBRUARY 1973

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied February 1973. Other requests for this document must be referred to the Air Force Armament Laboratory (DLIW), Eglin Air Force Base, Florida 32542.

AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

Development Of A Miniature All-Secondary-Explosive, Low-Voltage, Electric Detonator

E. A. Day

P. B. Ritter

G. E. Seay

FOREWORD

This final report documents work performed during the period 9 May 1972 through 30 January 1973 by Systems, Science and Software, P.O. Box 1620, La Jolla, California, under Contract F08635-72-C-0165 with the Air Force Armament Laboratory, Air Force Systems Command, Eglin Air Force Base, Florida. Dr. Martin F. Zimmer (DLIW) managed the program for the Armament Laboratory.

Air Force testing of prototype detonators furnished under this program was accomplished by personnel of the AFATL Explosive Dynamics Laboratory, Eglin Air Force Base, Florida, under the direction of Mr. James C. Jones III.

This technical report has been reviewed and is approved.

FRANKLIN C. DAVIES, Colonel, USAF
Chief, Flame, Incendiary, and Explosives Division

ABSTRACT

An operationally reliable miniature version of an all-secondary-explosive, low-voltage electric detonator has been developed and produced in test quantities. This safe detonator is based on the design which earlier was proven feasible. The detonator consists essentially of a donor explosive combustion chamber, an impactor disc, an airgap, and an acceptor explosive column which provides for proper coupling of the following three critical processes:

(1) Hot-wire initiation of a self-sustaining deflagration in a donor secondary explosive.

(2) Release and acceleration of a metal impactor disc by confined product gases of the deflagration in the donor secondary explosive.

(3) Shock initiation-to-detonation of an acceptor secondary explosive upon impact by the accelerated impactor disc.

It was found that the third process was mechanically separable from the first two. By separating it, detonator size can be reduced so that the first and second processes can be fitted to the FMU-1X fuze rotor while the third process can become part of the booster. The design parameters which control the critical process are discussed. A static fix of the assembly to make the detonator safe in a fast cook-off situation was demonstrated. Sensitivity to electromagnetic radiation loading is discussed. Prototype detonators furnished under this program were function tested by the Armament Laboratory. The results of these tests are included in Appendix III.

(The reverse of this page is blank)

TABLE OF CONTENTS

(The reverse of this page is blank.)

SECTION I

INTRODUCTION

The objective of this program was to develop a detonator compatible with the FMU-1X impact, short delay fuze system, which is currently under development. The detonator was to contain no primary explosive. The detonator was to function on the principle of hot wire initiation-to-deflagration of a secondary explosive donor charge. The deflagration-to-detonation transition within the detonator was to be accomplished by means of a high-velocity plate propelled by the donor charge and impacting on an acceptor booster explosive charge. The operational feasibility of a detonator with these functional characteristics had been demonstrated in an earlier program[1].

The scope of the effort was to include the design, development, evaluation, and fabrication of a low voltage, all-secondary-explosive detonator. The design of the detonator was directed toward miniaturization required for utilization in the FMU-1X fuze.

Detonators normally consist of a spark or heat-sensitive primary explosive and a booster charge. The booster charge, which is a secondary explosive, provides the main impulse of the detonator. The primary explosive is usually lead azide, lead styphnate, or mercury fulminate.

The sensitivity of primary initiating explosives to shock, spark, and impact necessarily introduces hazards in manufacture and use, requiring elaborate precautions to insure safety in handling. Mercury fulminate is well known as being thermally unstable and has been replaced generally by lead azide. However, lead azide is susceptible to hydrolysis which, in the presence of copper, results in the formation of very sensitive corrosion products. Unless stored under proper conditions, therefore, detonators containing mercury fulminate or lead azide have a limited shelf life. Lead styphnate is much more stable chemically but presents serious hazards due to its sensitivity to electrostatic charge under conditions now known to exist in some types of electric detonators[2].

In addition, primary explosives, with a few exceptions, do not burn; they detonate. Friction and fire can lead to detonation in adjoining secondary explosives. The high sensitivity of primary explosives dictates that detonators be handled and stored separately from munitions whenever possible.

Secondary explosives show much reduced mechanical sensitivity, good chemical stability, and, in general, very little hazard associated with electrostatic conditions. The use of only secondary explosives in detonators would reduce the hazards of handling detonators to the same level as handling the main charge. With suitable high-initiation levels and simple shuttering (explosive train interruptor), a detonator containing only secondary explosives could be safely mated with munitions during manufacturing, greatly simplifying logistics and field handling of such munitions.

One possible solution to these problems is an exploding wire detonator which contains no primary explosive and which requires a tailored electrical pulse to properly explode the wire and cause initiation of detonation. These devices, with properly designed high-voltage/power/energy sources and switch assemblies, are costly and complex when compared to hot-wire detonators and associated low-voltage/power/energy supplies. Their use would impose significant changes in the power supply and firing circuit of conventional fuze system.

This report describes the design, development, evaluation, and fabrication of a miniature size all-secondary-explosive detonator; it also describes minor modifications to the FMU-1X fuze to make it accept the detonator.

The safety of the detonator against nonprogrammed detonation in high-temperature environments is discussed, and the results of fast cook-off tests are presented.

Air Force testing of prototype detonators furnished under this program is documented in Appendix III.

SECTION II

MINIATURE SAFE DETONATOR DEVELOPMENT PROGRAM

A. DESIGN SPECIFICATIONS

The development of a safe detonator compatible with the FMU-1X fuze and based on the concept and principle of the all-secondary-explosive electric detonator shown in contractor drawing 3S144100, and shown in Figure 1, was to meet the following design specifications:

1. Safety. The detonator design shall meet all criteria of MIL-STD-1316.

2. Materials. The materials used to fabricate metal parts for the detonator shall conform to paragraphs 5.2 and 5.3 of MIL-STD-320. Non-permissible couples defined in MIL-STD-889 shall not be used. Explosives for the donor charge shall be no more sensitive to shock, friction, or spark than HMX or RDX. The acceptor charge shall be one of the materials listed as acceptable booster explosives in MIL-STD-1316.

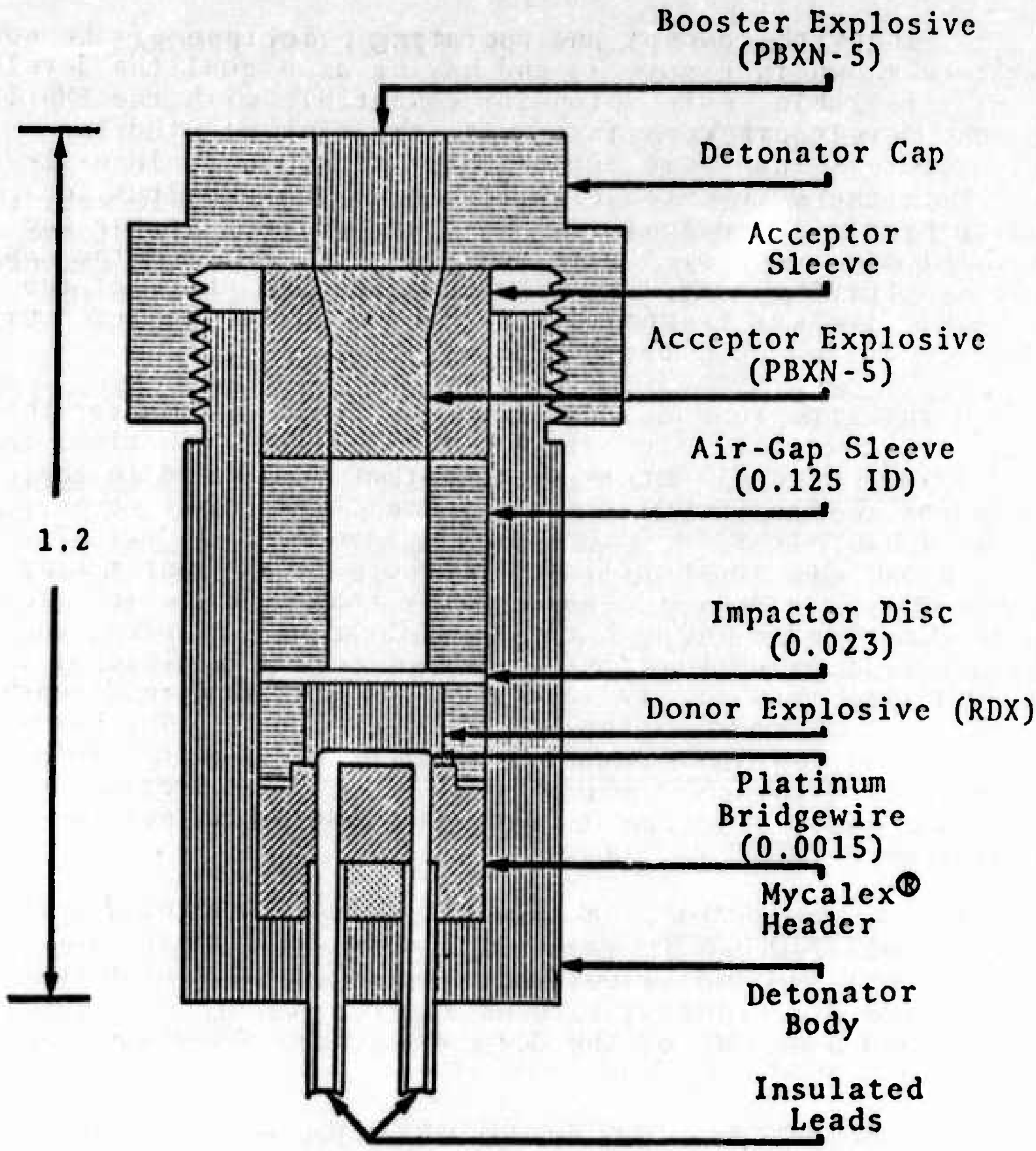
3. Desired Dimensions and Power Requirements. The detonator shall fit into the available space in the FMU-1X fuze rotor and shall function on the power available for detonator initiation.

4. Function Time. A detonator function time of less than one millisecond is required. A function time of less than 0.5 millisecond is desired. Function time is defined as the time differential between application of the firing current and breakout of the detonation wave from the acceptor charge.

5. Shelf Life. The design objective for this detonator is a minimum 10-year shelf life.

6. Performance. The detonator shall produce dents in excess of 0.010 inch, in accordance with Test 301, MIL-STD-331, to be acceptable.

7. Fast Cook-off. The enveloping-flame thermal environment conditions of 1800 ±200°F set forth in Naval Weapons Requirements, Warhead Safety Tests, WR-50, 13 February 1964, will be used to assess detonator cook-off characteristics.



Note: All dimensions in inches

Figure 1. Configuration of Detonator Designated in Contractor Drawing 3S144100

B. DESIGN PARAMETERS

Starting with concept and operating principle of the configuration shown in Figure 1, and having as a goal the development of a reliable, safe detonator compatible with the FMU-1X fuze, the developers were faced with the task of studying more parameters than were economically feasible to investigate. With the documented experiences of the previous feasibility program[1] and Reithel,[3] it was decided to use the same donor and acceptor explosives; that is, RDX for the donor and PBXN-5 for the acceptor. The quantity and shape of the donor explosive was essentially unchanged while the acceptor geometry required considerable adjustment.

For the same reasons, platinum was again chosen for the bridge wire material. To effect a shorter function time, the use of bridge wire diameters smaller than that used in the feasibility design (0.0015-inch diameter) were considered. Only one alternate size (0.0010-inch diameter) was actually tested, resulting in insufficient success to warrant making time measurements. Parameter changes other than changes in bridge wire diameter and/or length caused additional failures, and program schedule restrictions would not permit additional tests to investigate sensitivity to changes of bridge wire dimensions once a reliable donor system had been developed. The header was redesigned to minimize material creep which could relax confinement of the donor explosive. Also, the material used for making impactor or flyer discs was changed as well as disc size and method of support.

The air gap, determined by dimensions of the barrel through which the impactor disc flies, was varied in diameter and length, and the barrel surfaces were reamed to a smooth finish.

The case was reduced in size, and different methods of donor explosive confinement were tried.

One of the more important findings of this program lies in the fact that the acceptor explosive need not be incorporated within the barrel for the impactor to initiate a high-order detonation. High-order detonation was achieved in one test where the acceptor explosive had been separated from the end of the barrel muzzle by a 0.054-inch air gap plus a 0.020-inch thickness of stainless steel. (Test No. M-118, see Table I.) The same conditions prevented a high-order detonation in Test No. M-123. Successful detonations were achieved with air gaps up to 0.066 inch (M-107). Broader gaps have not been investigated. However, when gaps were blocked with the following materials, high-order detonations were prevented: 0.063-inch fiberglass/epoxy (M-109 and M-119), 0.060-inch stainless steel

TABLE I. LIST OF TEST FIRINGS

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-1	3S144100	Per Fig. 1 0.15L flyer travel	To prove effect of shorter fly distance	Fired*	Hi Order	
M-2	3S144100	Per Fig. 1 0.076D x 0.15 Flyer dia. & travel	To prove smaller dia. flyer	Fired	No	
M-3	3S144100	Same as M-2 except flyer disc reduced to 0.015" from 0.023"	To find workable SS flyer thickness	No Fire**	----***	Bridge wire burned with small burn spot in RDX confinement not adequate
M-4	3S144100	Repeat of M-3		Fired	No	
M-5	3S144100	Reduced flyer thickness to 0.012"		No Fire	----	Same as M-3
M-6	3S144100	Repeat of M-5		No Fire	----	Same as M-3
M-7	3S144100	Repeat of M-6		Fired	Hi Order	
M-8	3S144100	Repeat of M-7		Fired	Hi Order	
M-9	IV	Body, Header & Acceptor redesigned. Donor & flyer equal to M-8 Bridge wire damage 0.001	To determine effect of swaged body to confine donor explosive	No Fire		Bridge wire gone, RDX not discolored
M-10	IV	Same as M-9 with flyer thickness reduced from 0.012" to 0.010"		No Fire	----	Bridge wire gone, RDX slightly discolored

*Indicates RDX donor burned and caused flyer disc to rupture and accelerate down gun barrel.
**Indicates flyer disc was not ruptured and accelerated.
***Receiver/booster is detonated by impact of the flyer disc in normal operation. When flyer disc is not accelerated, no response of the receiver/booster is possible. The dashes (----) indicate this latter condition.

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-11	IV	Same as M-9 with flyer thickness reduced from 0.010" to 0.007"		No Fire	----	Bridge wire gone, RDX slightly discolored
M-12	IV	Swaged body, 0.001" bridge wire, flyer ~0.13Dx0.012T		No Fire	----	Burn marks not pronounced on RDX
M-13	IV	Same as M-12 except with 0.0015" bridge wire & 0.156"D flyer		No Fire	----	Same
M-14	IV	Same as M-13		No Fire		Same
M-15	IV	Same as M-14 except no acceptor or booster. Assembly clamped in vise	To check confinement of RDX by swaging	Fired	N.A.	Disc made crater in vise jaw
M-16	IV	Same as M-15 with acceptor & booster		Fired	No	
M-17	IV	Same as M-16 with flyer thickness reduced from 0.012" to 0.010"		Fired	No	
M-18	IV	Same as M-17 with flyer thickness reduced from 0.010" to 0.007"		Fired	No	
M-19	IV	Same as M-18 with bridge wire 0.001"D and flyer 0.156" by 0.012"T		Fired	No	
M-20	IV	Same as M-19 with header change, bridge wire 0.001", flyer 0.12" x 0.010"		Fired	No	

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-21	IV	SS/FG header, 0.0015" bridge wire, 0.156"x 0.010", Flyer, 0.100g RDX donor	Check increased donor charge	Fired	No	
M-22	IV	Same as M-21 except 0.012" flyer		Fired	No	
M-23	IV	Bridge wire 0.0015, 0.076"Dx0.010" flyer vise confined 50 mg RDX		Fired	No	
M-24	IV	Same as M-23 with 0.30"L acceptor		Fired	No	
M-25	IV	Same as M-24 with 0.012" flyer		Fired	No	
M-26	IV	Same as M-25 with 85 mg RDX		Fired	Hi Order	
M-27	IV	Same as M-26 with 100 mg RDX screw confined-not in vise	Determine the effectiveness of 10-32 UNF screw confinement of donor	Fired	No	Body split
M-28	IV	Same as M-27 with 120 mg RDX, screwed assembly held in vise	Varied quantity of RDX	Fired	No	Body split
M-29	IV	Same as M-28	Varied quantity of RDX	Fired	No	Body split
M-29A	IV	Same as M-28 with 50 mg donor predimpled flyer, vise confined		Fired	No	

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-30	IV	Repeat of M-26		Fired	No	
M-31	IV	Repeat of M-26		Fired	No	Body bulged, did not split
M-32	IV	Flyer 0.076"Dx0.015"T Donor 50 mg, screw confined, acceptor 0.076"Dx0.15"L		Fired	No	
M-33	IV	Body slotted-side leads, screw confined, flyer 0.012"Tx0.076"D, flyer distance 0.15", bridge wire 0.0015"D, donor 50mg RDX, acceptor 0.076"x0.250"L		Fired	No	
M-34	IV	Same as M-33, reinforced ring added		Fired	No	
M-35	IV	Center leads, screw confined, acceptor 0.076"x0.225", donor 85 mg RDX, otherwise like M-33		No Fire	----	Bridge wire open at one terminal
M-36	IV	M-35 Re Do		Fired	No	Case split
M-37	IV	Same as M-35 with body reinforced ring added		Fired	No	Ring held body intact
M-38	IV	Same as M-37 with acceptor 0.076"x 0.300"		Fired	No	Case intact
M-39	IV	Same as M-37 with a 3-hole acceptor block used	To produce shock interaction in the PBXN-5	No Fire	----	Bridge wire failed. Hole in Fiberglas disc near terminal

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-40	IV	Repeat of M-39		Fired	No	
M-41	VI	Body 0.375"o.d.x 0.213"i.d., donor 0.100"Dx0.213"L 85 mg Acceptor 0.076" x 0.275", Flyer 0.012" x 0.076"D, Fly Distance 0.150"	To make donor aspect ratio & size equal to M-7 & M-8, successful configurations 24 LBIN torque			
M-42	VI	Repeat of M-41, torqued to 50 LBIN		Fired	No	
M-43	VI	Same as M-42 with flyer increased to 0.015"T	Effect of flyer disc thickness	Fired	No	
M-44	VI	Same as M-42 with acceptor length 0.375"	Effect of acceptor HE length	Fired	Hi Order	
M-45	VI	Same as M-44 with acceptor 0.300"L with conical far end		Fired	No	
M-46	VI	Same as M-45 with flyer thickness 0.015"		Fired	No	
M-47	VI	Same as M-44 with flyer thickness 0.015"		Fired	No	
M-48	VI	Same as M-44 with acceptor 0.375 with conical far end		Fired	No	
M-49	3S144100	Repeat of M-7, 200 LBIN torque	To try to reproduce results of early tests	No Fire	----	
M-50	3S144100	Repeat of M-49		Fired	No	
M-51	3S144100	Repeat of M-49 with torque 150 LBIN	Lost wrench fit	No Fire	----	Confinement in question.
M-52	3S144100	Repeat of M-49		No Fire	----	Confinement torquing difficult
M-53	VIB	Body 0.375"o.d.x 0.213"i.d., barrel/ acceptor threaded to confine donor, 1/4-28 thread torqued to 65 LBIN, acceptor 0.076"Dx0.275" with conical far end	All internal configuration equal to M-7	Fired	Hi Order	

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-54	VIB	Same as M-53 with torque increased to 80 LBIN		No Fire	----	
M-55	VIB	Same as M-53		Fired	No	
M-56	VIB	Same as M-53		No Fire	----	
M-56A	VIB	Same as M-53 with torque at 75 LBIN		Fired	No	
M-57	V	Body 0.290"o.d.x 0.159"i.d., barrel/ acceptor threaded to confine donor. 10-32 UNF threads torqued to 50 LBIN, acceptor 0.076"D x 0.275"L with conical far end, flyer 0.012, fly distance 0.150"	To investigate possibility of small diameter body	Fired	No	Body split
M-58	V	Same as M-57 with flyer disc pin-dimpled and body reinforced with sleeve	Effect of local shock interaction in PBXN-5 caused by dimpled flyer. Reinforcement to hold body together to maximize flyer velocity	Fired	No	Body held intact
M-59	V	Same as M-58 with acceptor 0.300"L		Fired	No	Acceptor head sheared upon torquing
M-60	V	Same as M-58 with acceptor 0.38"L plain flyer		Fired	No	
M-61	VB	Same as M-58 with acceptor 0.38"L & reinforced booster added, flyer pin dimpled		Fired	No	
M-62	VB	Same as M-60 with ring reinforcing, flyer distance 0.10"		Fired	No	40 out of 47 stainless/ Fiberglas header fired accelerated the flyer discs
M-63	3S144100	Same as M-7	Repeat of successful configuration, old header/donor design	No Fire	----	

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-64	VII	Body 0.375o.d.x 0.213i.d., 1/4-28 UNF screw confined barrel & straight acceptor threaded barrel 0.125x0.150 flyer 0.025 SS, acceptor 0.125"Dx 0.275"L, torque 50 LBIN,with booster	Try larger flyer diameter	Fired	No	
M-65	VII	Same as M-64 without booster		Fired	?†	Acceptor marginal, 0.005" dent in witness block
M-66	VII	Same as M-65		Fired	No	No dent, acceptor hex disintegrated
M-67	VII	Same as M-65 with confined cyl-to-cone booster		Fired	No	
M-68	VII	Same as M-67 except barrel & acceptor diameter reduced to 0.100", flyer 0.125"D x 0.020"T with retaining sleeve		Fired	Hi Order	Good dent in witness block
M-69	VII	Same as M-68, restraining sleeve added		Fired	Hi Order	Good dent in witness block
M-70	VII	Same as M-69 except 0.015" spacer (air) added between acceptor & booster	To show that detonation will continue across clearance between fuse & charge	Fired	Hi Order	Good dent
M-71	VII	Same as M-69 except a train 0.100"D to 220" diameter x0.30L added between acceptor and bare booster		Fired	No	
M-72	VII & VIII	Similar to M-69 except acceptor 0.076"D to 0.170D x 0.275L, flyer 0.025"T x 0.125"D		Fired	No	

†Question mark indicates question of detonation of Receiver/Booster. 0.010-inch indentation of steel witness block is prescribed limit for satisfactory operation.

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-73	VII	Same as M-69 except fly distance is 0.100" & acceptor 0.325"L, flyer 0.020"T x 0.125"D	Effect of fly distance	Fired	Hi Order	
M-74	VII	Same as M-73 except fly-distance is 0.070" & acceptor is 0.355	Effect of fly distance	Fired	No	
M-75	VIII	Body 0.320"o.d. x 0.213"i.d., 1/4-28 UNF thread, flyer 0.020"T x 0.10D fly distance 0.120, acceptor 0.100D x 0.255L, 0.014 gap between booster		Fired	No	Body parted in donor region
M-76	VII	Body 0.375"o.d. x 0.213i.d., acceptor 0.10"D x 0.305"L, 0.015 gap booster		Fired	No	
M-77	VII	Same as M-76 with 0.375"L, booster added	M-76 looked marginal, booster added to verify	Fired	No	
M-78	VII	Same as M-77		Fired	No	
M-79	VII	Same as M-77 except no gap between acceptor & booster		Fired	No	
M-80	VII	Same as M-77 except fly distance 0.150" acceptor 0.10"D x 0.275"L		Fired	No	

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-81	VIII	Same as M-75 except acceptor 0.305"L, no gap		Fired	No	Marginal. No dent in witness block
M-82	VIII	Same as M-81 with 0.375D booster added		Fired	No	
M-83	VIII	Same as M-81 except 0.125D to 0.20D x 0.25L booster in 3/8o.d. SS in stepped Al sleeve		Fired	Hi Order	
M-84	VIII	Same as M-83		Fired	No	
M-85	VIII	Similar to M-83 except conical booster omitted in Al block, solder fuse plug	Fuse plug to relieve confinement in fire situation	Fired	No	
M-86	VIII	Same as M-85 with 3/8"D booster added		Fired	No	
M-87	VIII	Body 0.320"o.d.x 0.213"i.d., flyer 0.025"Tx0.125D, fly length 0.425", acceptor 0.125"D with 15° inc. angle taper 0.5"L, no booster	Effect of gradual taper	Fired	No	
M-88	VIII	Body 0.320"o.d. x 0.213"i.d., flyer 0.020"T x 0.100"D, flight length 0.125", acceptor 0.100"D x 0.63"L		Fired	No	
M-89	VIII	Same as M-87 except flyer 0.020"T		Fired	Hi Order	Good dent

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-90	VIII	Same as M-89		Fired	Hi Order	Good dent
M-91	VIII	Same as M-89 with 0.010 SS shim cover over acceptor	To show detonation through acceptor cover	Fired	No	0.020 SS flyer welded to 0.010 acceptor cover
M-92	VIII	Same as M-89 with 0.003 Al foil over acceptor	Same	Fired	No	
M-93	VIII	Repeat of M-89		Fired	No	Flyer tumbled!
M-94	VIII	Same as M-88 with 1"o.d. Al sleeve added		Fired	No	
M-95	VIII	Same as M-89 without acceptor	To observe condition of flyer impact on witness block	Fired	NA	Flyer impact made crater ~0.03" deep, flyer impact not flat-tended to fold, flyer welded in witness block crater
M-96	VIII	Same as M-89, flyer 0.100"D x 0.020"T Flight length 0.75" no acceptor	Same	Fired	NA	Slightly non-parallel, imbedded & welded in crater
M-97	VIII	Same as M-89, flyer 0.020"T x 0.100"D flight length 0.442" no acceptor	Same	Fired	NA	Impact looked parallel, disc welded in crater
M-98	VIII	Same as M-89, flyer 0.020"T x 0.100"D flight length 0.428" acceptor 0.125"D to 0.20"D x 0.25L		Fired	No	
M-99	VIII	Same as M-89, flyer 0.020" x 0.100", flight distance 0.750, acceptor 0.076"D to 0.20"D x 0.375"L confined in 1" o.d.Al sleeve & clamped in vise		Fired	Hi Order	
M-100	VIII	Repeat of M-99		Fired	No	Acceptor HE burned. Disc marks at acceptor entrance indicate disc angle impact
M-101	VIII	Same as M-99 except flight distance 0.425"		Fired	No	

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-102	VIII	Same as M-101 except flyer was 0.050" Al Alloy 6061-T6	Check effect of thicker flyer slug	Fired	Hi Order	Good dent, ~0.025" deep
M-103	VIII	Repeat M-102		Fired	Hi Order	
M-104	VIII	Repeat M-102		Fired	Hi Order	
M-105	VIII	Same as M-102 flight length 0.375 1-3/8 o.d. steel sleeve	To check 0.05 Al alloy flyer	Fired	Hi Order	
M-106	VIII	Repeat M-105		Fired	Hi Order	
M-107	VIII	Same as M-105 with 0.066" air gap between barrel muzzle & acceptor HE	Effect of gap	Fired	Hi Order	
M-108	VIII	Repeat of M-107		Fired	Hi Order	
M-109	VIII	Same as M-105 except 0.063"T Fiberglas filled epoxy sheet between muzzle and acceptor HE	To determine the effect of a F/E barrier	Fired	No	Fiberglas/epoxy prevented hi order detonation, acceptor did burn, no dent in witness block
M-110	VIII	Same as M-107 except donor body contained a solder fuse plug, gap was 0.064"	To determine the effect on donor function of a fuse plug	Fired	Hi Order	
M-111	VIII	Same as M-107 except flight distance was 0.240" & air gap was 0.064"	Test shorter flight of impactor disc	Fired	Hi Order	
M-112	VIII	Same as M-107 except that no gap, instead 0.0055" thick SS shim covered the acceptor explosive	To test the possible use of a metal seal over acceptor	Fired	Hi Order	
M-113	VIII	Same as M-107 except the air gap was 0.064" & a 0.0055" SS shim covered the acceptor, the donor body contained a fuse plug	To test effect of a fuse plug & to determine the effect of an air gap in front of a sealed acceptor explosive	Fired	Hi Order	
M-114	IX	Same as M-107 except body o.d. was 0.375", flight 0.160", gap 0.054", acceptor cover 0.0055" SS	To test shorter flight distance	Fired	Hi Order	

TABLE I (continued)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-115	IX	Same as M-107 except flight was 0.420", acceptor cover 0.0055" SS, acceptor 0.25" diameter cyl x 0.375"L	Test effect of large diameter acceptor	Fired	Hi Order	
M-116	IX	Same as M-107 except flight was 0.430" & receiver was covered with 0.06" SS (3 - 0.020" shims)	Test stopping effect of 0.06 SS barrier	Fired	No	PBXN-5 burned but did not detonate
M-117	IX	Same as M-107 except flight ~ 0.420", gap was 0.054", acceptor was covered with 0.012 SS	Test stopping effect of SS shim	Fired	Hi Order	
M-118	IX	Same as M-117 except 0.020" SS shim used	Same	Fired	Hi Order	
M-119	IX	Body 0.375" o.d. x 0.213" i.d., flyer 0.050" Al x 0.100"D, flight 0.42", acceptor 0.25"D x 0.375"L, 0.063" Fiberglas/ epoxy over acceptor	To test stopping effect of F/E barrier over large PBXN-5 area	Fired	No	PBXN-5 burned but did not detonate
M-120	IX	Same as M-119 except 0.054" gap & 0.035" (0.015" + 0.020") SS cover over acceptor	To test effect of gap + SS barrier	Fired	No	PBXN-5 burned
M-121	IX	Same as M-119 except 0.081" gap & 0.020" SS cover over acceptor		Fired	No	PBXN-5 burned

TABLE I (concluded)

Test No.	Type	Description	Purpose	Donor	Receiver/ Booster	Remarks
M-122	IX	Same as M-119 except 0.054" gap & 0.0055" SS cover over acceptor flight distance 0.16	To test effect of gap & thin barrier over large diameter (0.25) of acceptor & short flight distance	Fired	No	PBXN-5 burned
M-123	IX	Same as M-119 except 0.054" gap & 0.020" SS cover over acceptor	Test gap with intermediate thickness barrier	Fired	No	PBXN-5 burned
M-124	3S185100	3S185100 fired in 3S185120 sleeve	Proof test of deliverable item	Fired	Hi Order	
M-125	3S185100	3S185100 fired in 3S185120 sleeve fitted with 3/4" diameter F/E sleeve to simulate rotor of FMU-1X fuse rotor	To prove function of detonator in non-metal confinement	Fired	Hi Order	
M-126	3S185100	3S185100 fired in 3S18[illegible] sleeve	Same as M-124	Fired	Hi Order	Poor fit of detonator in sleeve but functioned OK
M-127	3S185100	Repeat of M-125		Fired	Hi Order	
M-128	X	3S185100 bare (no sleeve) taped to 0.076"D to 0.20"D x 0.25"L encased acceptor (PBXN-5)	To determine the need for body confinement	Fired	Hi Order	
M-129	X	Repeat of M-128		Fired	Hi Order	Sleeve not required for donor to function
M-130	X	3S185100 fired in 3S185120 sleeve	Determine effect of 28 day aging (torque not checked) measure function time	Fired	No	Function time ~375 μsec
M-131	X	Same	Retorqued to 60 LBIN (~1/8 turn required)	Fired	Hi Order	Function time = 200 μsec
M-132	X	Same	Same	Fired	Hi Order	Function time = 180 μsec
M-133	X	Same except firing current was 1 ampere (instead of ~10 amps)	Same	Fired	Hi Order	Function time > 1 msec
M-134	X					

(M-116), 0.054-inch air gap plus 0.035-inch stainless steel (M-120) and 0.081-inch air gap plus 0.020-inch stainless steel (M-121).

The acceptor explosive (PBXN-5) powder compressed by 20,000 psi pressure to a density of 1.67 gm/cc, was tested in a range of shapes from unconfined cylindrical blocks with diameters much larger than the impactor disc diameter, to sleeve-confined pressings with diameters smaller than the impactor disc. The configuration which proved the most reliable and consistent in producing > 0.020-inch dents in standard steel witness blocks was a confined cylindrical section with diameter equal to, or less than, the impactor disc diameter, followed by a conical section flaring to a larger diameter at the output end.

C. DEVELOPMENT TEST PROGRAM

The starting point for developing the reliable, miniature version of the safe detonator was the product of the feasibility program which is shown in Figure 1. The feasibility program was a success and pointed to the areas where reliability improvements could be made. Donor ignition was one such area, and acceptor initiation and detonation was another. It was understood at the beginning of the current program that reliability control, as well as size reduction, was important to the development of a useful detonator.

During fourteen series of tests, over 130 firings were performed. The first series was dedicated to the reduction of impact disc diameter and flight distance. Test No. M-1 proved that the flight distance could be successfully reduced to 0.15 inch, and tests Nos. M-7 and M-8 indicated 0.076 inch was a functional diameter for a 0.012-inch-thick stainless steel impactor disc. The basic hardware shown in Figure 1 was used for this test series.

A general redesign was than undertaken to reduce the overall dimensions while incorporating these proven reduced sizes for the flyer disc and flight distance. The screw cap was eliminated, and confinement of the donor explosive was accomplished by crimping the header end of the body while the assembly was under compression in the press. A stainless steel header capped with a thin (0.010-inch) Fiberglass/epoxy sheet insulator was designed to provide backup strong enough to allow crimping of the body. The header diameter was reduced as well as the spacing between the lead posts. Two bridge wire configurations were used: one was a straight wire of 0.0010-inch diameter platinum; the other was a 0.0015-inch-diameter platinum wire formed into a W-shaped pattern. Both had an electrical resistance of about 0.3 ohm. In both configurations the bridge wire was mounted flush against the insulating portion of the header. Soft solder was used to bond the bridge wires to the lead ends which had been finished flush with the header. The flyer disc was constrained on the donor face only by the compressed explosive where previously it had been peripherially clamped by an aluminum donor sleeve. In this way the donor sleeve of the previous design was eliminated, and a reduction in body diameter was possible.

The results of the three tests of the second series and the first three tests of the third series were negative. The RDX donor explosive did not ignite, and only slight discolorations appeared at the point of bridge wire burnout. This occurred with both bridge wire diameters. A review of the test parameter and technique changes caused by the redesign indicated that there was a serious question about the residual donor confinement after the crimping operation. Test assemblies than were set up in a drill press table vise so that positive confinement could be assured. The first test did not contain an acceptor explosive section. The donor ignited, rupturing the flyer disc and accelerating it down the barrel. Fifteen tests were fired using vise confinement, with only one high-order detonation of the acceptor explosive. All fifteen vise-clamped assemblies, as well as two screw-confined assemblies resulted in donor ignition with flyer acceleration. Conditions of the single successful high-order test were repeated several times without repetition of acceptor detonation.

Conversion to a design employing screw confinement with internal threads at the receiver end resulted in very successful and reliable donor ignition. However, high-order detonations of the acceptor/booster explosive were only sporadic at best.

Variations of donor cavity strength, stainless steel flyer disc thickness and diameter, and gap distance were all futile. Only occasional high-order detonations were achieved. Several impactor discs had been recovered and inspection indicated these had apparently traveled the barrel without tumbling. However, tumbling of the flyer discs appeared to be a possible cause for the sporadic results. Therefore, in test series No. 10, three tests were set up to observe the impact craters in recovered witness plates placed at the muzzle of the barrel. No acceptor explosive was used. The results showed that all of the 0.020-inch-thick stainless steel discs impacted with sufficient force to become embedded in the steel witness blocks to depths greater than their thickness. One disc (Test No. M-97) showed a very symmetrical impact condition. Test No. M-96 was slightly asymmetrical, and Test No. M-95 showed that the disc had started to fold during the cratering impact. These three tests indicated only slight tumbling occurred with travel distances of 0.42, 0.75, and 0.44 inch.

Tests M-99 and M-100 were identical with 0.100-inch-diameter by 0.020-inch-thick stainless steel flyer traveling 0.75 inch, impacting a tapered acceptor charge in a stainless sleeve with a 0.076-inch-diameter charge surface at the impact end. M-99 resulted in a high-order detonation of the acceptor while M-100 did not. Although the acceptor explosive burned, without detonating in Test No. M-100, the impact end of the sleeve remained intact, and flyer disc impact marks showed that the disc impacted at an appreciable angle with respect to the acceptor sleeve face. A similar condition was observed from recovered parts from Test No. M-101 which was similar to Test No. M-99 except that the fly distance was 0.42 inch and the acceptor surface diameter was 0.076 inch.

From these observations, it became apparent that thin stainless steel flyer discs are inclined to tumble and cannot induce detonation reliably in pressed PBXN-5 acceptor explosive when non-parallel impacts occur. A thicker flyer disc was an obvious solution with broader bearing contact along the barrel to resist or prevent tumbling, while limiting blow-by and subsequent velocity loss. The material most immediately available was aluminum. On a mass-per-unit-area basis, a 0.056-inch aluminum alloy would equal the 0.020-inch stainless steel flyer discs which had produced high-order detonations in confined PBXN-5 acceptor assemblies. A piece of 0.050-inch-thick 6061-T6 aluminum alloy was available from which flyer discs were hand punched. Test No. M-102 was identical to Test No. M-101 except for the change in flyer disc. The result was a high-order detonation. Repeats (Tests No. M-103 and No. M-104) of Test No. M-102 yielded two additional high-order detonations. Dents in steel witness blocks were 0.025, 0.027, and 0.027 inch deep.

A review of comparative strengths and thicknesses of the aluminum alloy and the stainless steel indicates that the disc punchout pressures for the two are essentially the same, approximately 50,000 psi. The mechanical properties of 6061-T6 and 5052-H38 are essentially equal so no problem is anticipated in the use of the latter, a MIL-STD-320 approved alloy, in lieu of the available 6061-T6 alloy.

The effect of flyer material on the impact shock strength can be estimated even though the shock Hugoniot for pressed

PBXN-5, ρ = 1.67 g/cc is not available. Hugoniot data for PBX 9404, ρ = 1.84 g/cc is given in Reference 4. However, the shock Hugoniot for PBXN-5, ρ = 1.67, is probably closer to that of HNS, ρ = 1.57(5), or RDX, ρ = 1.62 - 1.65(5). The nylon content of PBXN-5 and its void fraction will depress the modulus of the material. Assuming an impact velocity of 1 mm/μsec, Figure 2 gives an indication of the relative impact shock intensities of aluminum alloy and stainless steel on HNS or RDX pressings, which should be indicative of PBXN-5, ρ_o = 1.67. This indicates less than 20 percent lower shock pressure in the aluminum alloy/PBXN-5 impact, as compared with the stainless steel/PBXN-5 impact.

When the thin stainless steel flyer impacts normal to the PBXN-5 surface, the shock intensity is only 20 percent higher than in an aluminum alloy/PBXN-5 impact. The ratio of pulse durations for the 0.020-inch-thick stainless steel and 0.050 aluminum alloy is

$$r_t = \frac{2t_{SS}}{C_{o_{SS}}} / \frac{2t_{AA}}{C_{o_{AA}}}$$

$$= 0.46$$

where t is the thickness of the flyer and C_o is the shock velocity of the flyer material in consistent units.

Therefore, the aluminum of equal mass per unit area and equal pressure resistance to stainless steel will accelerate to the same velocity neglecting frictional differences and will produce an impact shock in PBXN-5 explosive of nearly equal intensity for more than twice the duration. The thick aluminum alloy flyers are restrained from tumbling and consequently should impact with reproducible velocities, while the thin stainless steel flyers are subject to tumbling and hence serious losses of impact velocity.

<u>Reliability of Operation</u> - Although the detonator has not been optimized for minimum size and economy of production, a configuration which shows considerable promise for reliable operation is shown in Figure 3. Two groups of twelve units each of this design were sent to the Air Force Armament Laboratory for evaluation. A report of those tests is given in Appendix III.

The header construction, consisting of stainless steel insulated with a fiberglass/epoxy cap and using a 0.0015-inch-diameter platinum bridge wire, and with adequate confinement

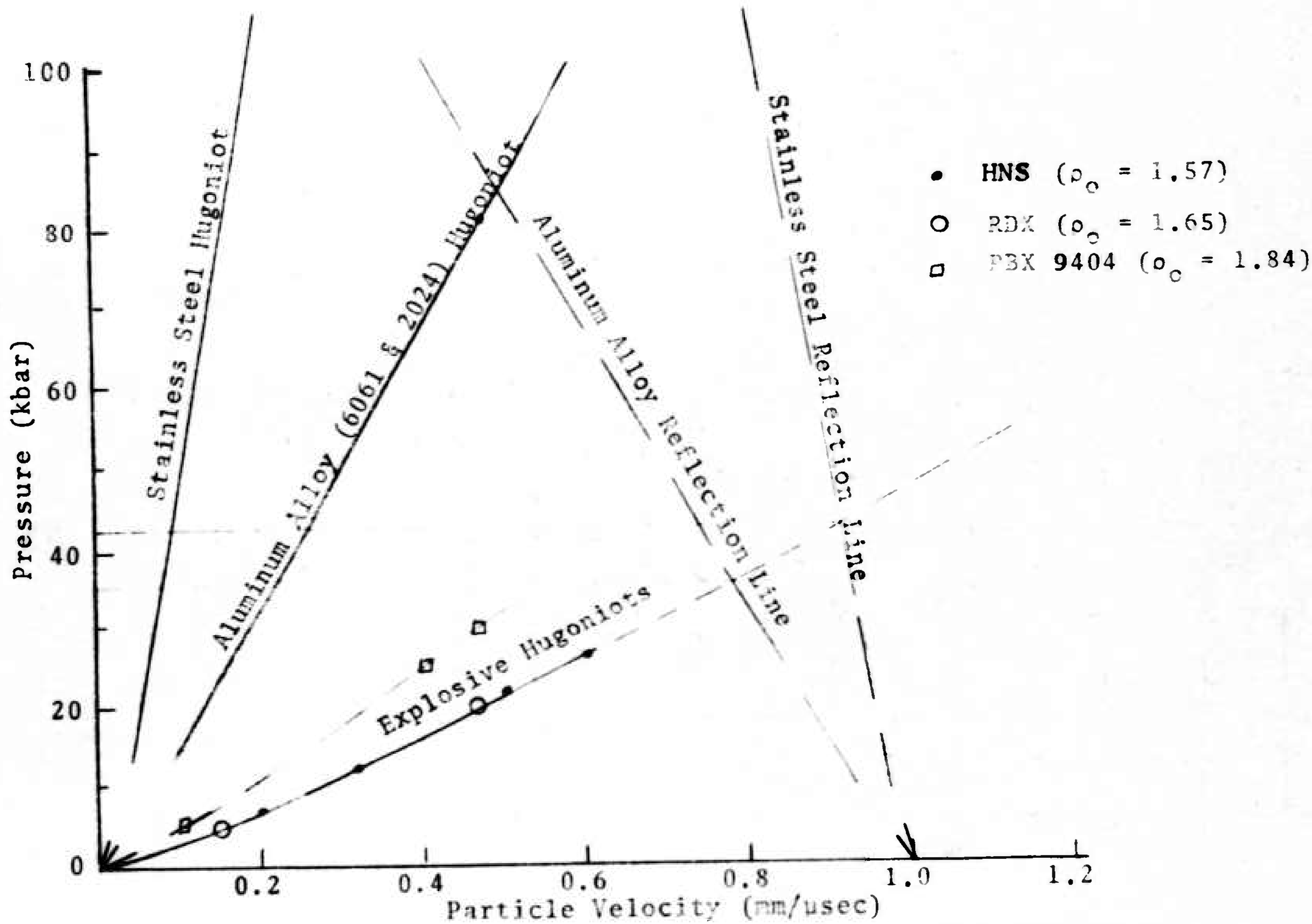
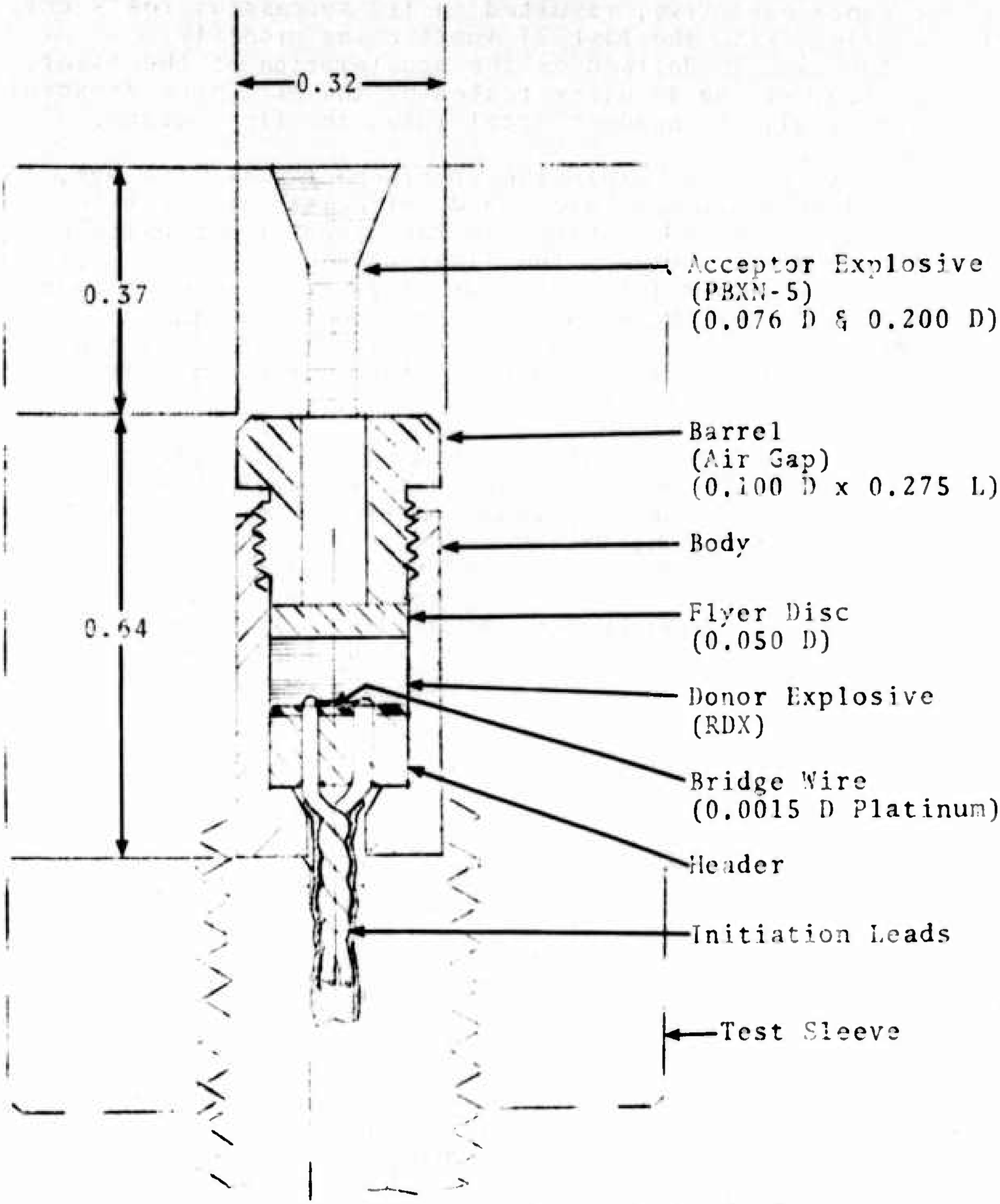


Figure 2. One Millimeter per Microsecond Impact Conditions for Stainless Steel and Aluminum Alloys (Data Linearized for Convenience) and Some Explosives



All Dimensions in Inches

Figure 3. All-Secondary-Explosive, Hot-Wire, Electric Detonator Model 3S185100 with Test Sleeve Containing Acceptor Explosive

of the donor explosive, resulted in 112 successful tests out of 116 tries, with the last 77 functioning properly. A proper function is defined as the acceleration of the flyer. In addition, of the 24 units tested by the Air Force Armament Laboratory, all the headers accelerated the flyer discs.

Except for donor explosive confinement loss with age, which will be discussed later, and deliberate attempts to prevent high-order detonations in the acceptor explosive by inserting barriers between the flyer disc and the acceptor explosive, 24 successful shots out of 24 tries were attained. In addition to the above, all 24 units tested by the Air Force Armament Laboratory achieved high-order detonation of the acceptor explosive, as indicated by the dent depth column of Appendix III, Table III-1.

The Effect of Aging - Twenty-eight days after fabrication, five detonators of the design shown in Figure 3 were tested for detonation, torque, and function time. One detonator was tested without checking the donor explosive confinement torque. The results indicated a failure of the acceptor PBXN-5 explosive to detonate, although the flyer disc had been accelerated. The acceptor explosive burned but no dent was produced in the witness block. The function time switch was actuated at 375 μsec after turn-on of firing circuit.

Torque was checked on the other four units; each required approximately 45° (1/8 turn) to bring the resistance back to the design value of 60 lb-in.

Two detonators were then tested with high-order detonations resulting in 200 and 180 μsec function times. The nominal 10-ampere firing current was used.

The fourth unit was tested using one ampere firing current with a high-order detonation occurring at a time greater than 10 msec, the limit of the oscilloscope setting.

The fifth unit was stored for further aging. After an additional 41-day period, the torque was again rechecked with a $6^{\circ}\ 7'$ rotation required to restore the 60 lb-in. value. After another 46-day period, the torque of this fifth unit was checked and a rotation of only $1^{\circ}\ 36'$ was required for restoration of the design value. The periods between the torque rechecks were purely a matter of convenience. The effects of such variables as the time period between retorquing and initial loading pressure on the donor explosive should be investigated. Figure 4 indicates the drastic reduction in creep of the compressed donor explosive with retorquing.

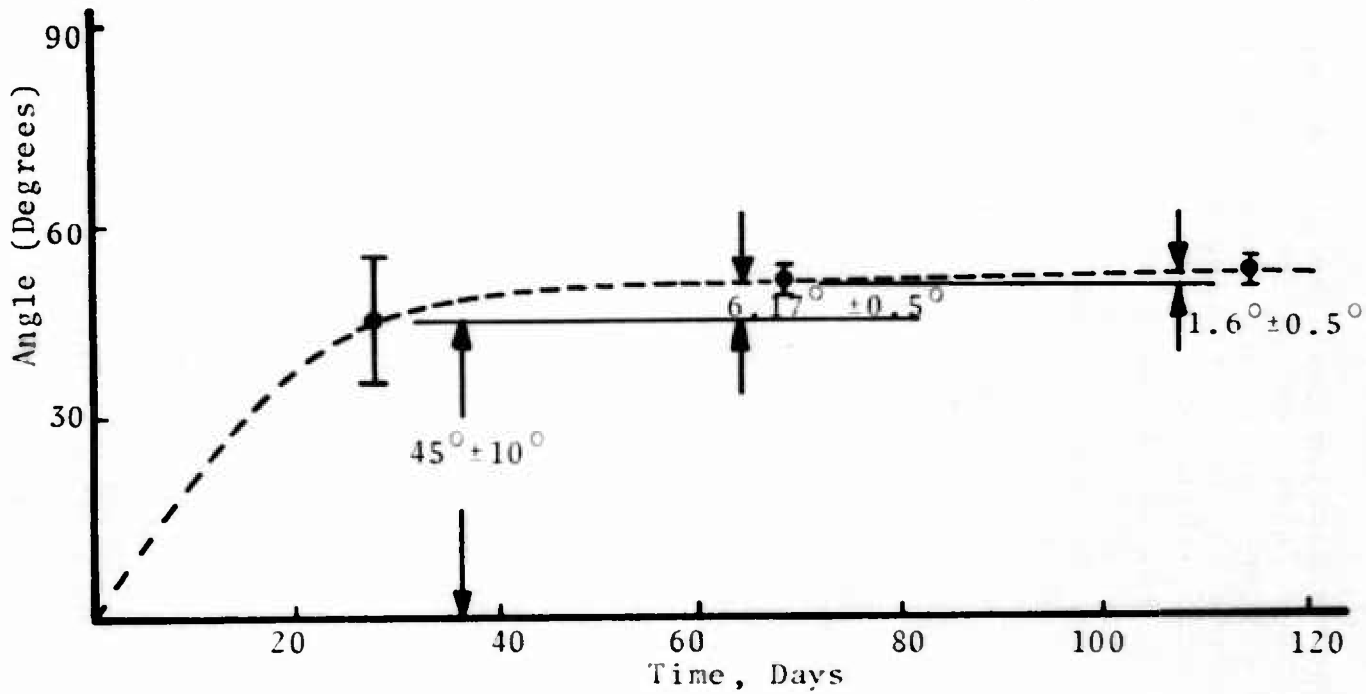


Figure 4. Torquing Angle Required to Restore Donor Confinement to a Torque Value of 60 lb-in. Versus Aging Time for Detonator Model 3S185100

Function Time - Function times were measured by the contractor and by personnel at the Air Force Armament Laboratory's Explosive Dynamics Laboratory. The technique used by contractor personnel is given in Appendix I and that used by Air Force personnel is given in Appendix III.

The technique using a normally open foil gap with a 300-VDC potential, which is shorted by the ionized plasma of the detonating explosive products, shows the more rapid response. It is believed that this method produces a reasonably accurate indication of the detonation breakout at the booster surface. Measured by the 300-volt gap shorting method, detonators, built as shown in Figure 3, had function times of approximately 200 μsec with 10 amperes peak initiating current, and greater than 10 msec when the initiating current was limited to one ampere. The combined detonator/booster function time specification for the FMU-1X fuze is 300-μsec maximum, with 100 μsec desired. Figure 5 shows a typical oscilloscope trace photograph of the initiation current versus time and the instant of closure of the foil switch located at the output end of the acceptor explosive. The maximum steady-state current which will not ignite the RDX donor explosive is yet to be determined. Figure 6 shows the function time versus initiation current.

Fast Cook-off Protection - The all-secondary-explosive, hot wire, electric detonator is inherently a safe detonator. Its construction includes epoxy cements which, in part, provide sealing and containment for the donor explosive. Upon heating, these cements degrade and defeat the confinement of the heating donor explosive, preventing the rupture of the flyer disc. The only restriction is that the heating rate must be limited by the detonator container or holder or fuze body, such that the epoxy has time to degrade. Tests showed the system to be safe when the body reached a relief temperature in about 100 seconds. One unit tested without the test sleeve (see Figure 3) raised in temperature so rapidly that confinement was maintained, and the decomposition products of the RDX were sufficiently confined to develop in 12 seconds the disc bursting pressure. Calibration runs on sheathed and bare units showed the sheathed unit to reach 500°F in 100 seconds and the bare unit 400°F in 12 seconds. The explosion temperatures of Cyclonite (RDX) at various soak times are given in Reference 6 as follows.

Seconds	°C(°F)
0.1	405 (762)
1.0	316 (600)
5.0 (decomposes)	260 (500)
10.0	240 (464)
15.0	235 (455)
20.0	---

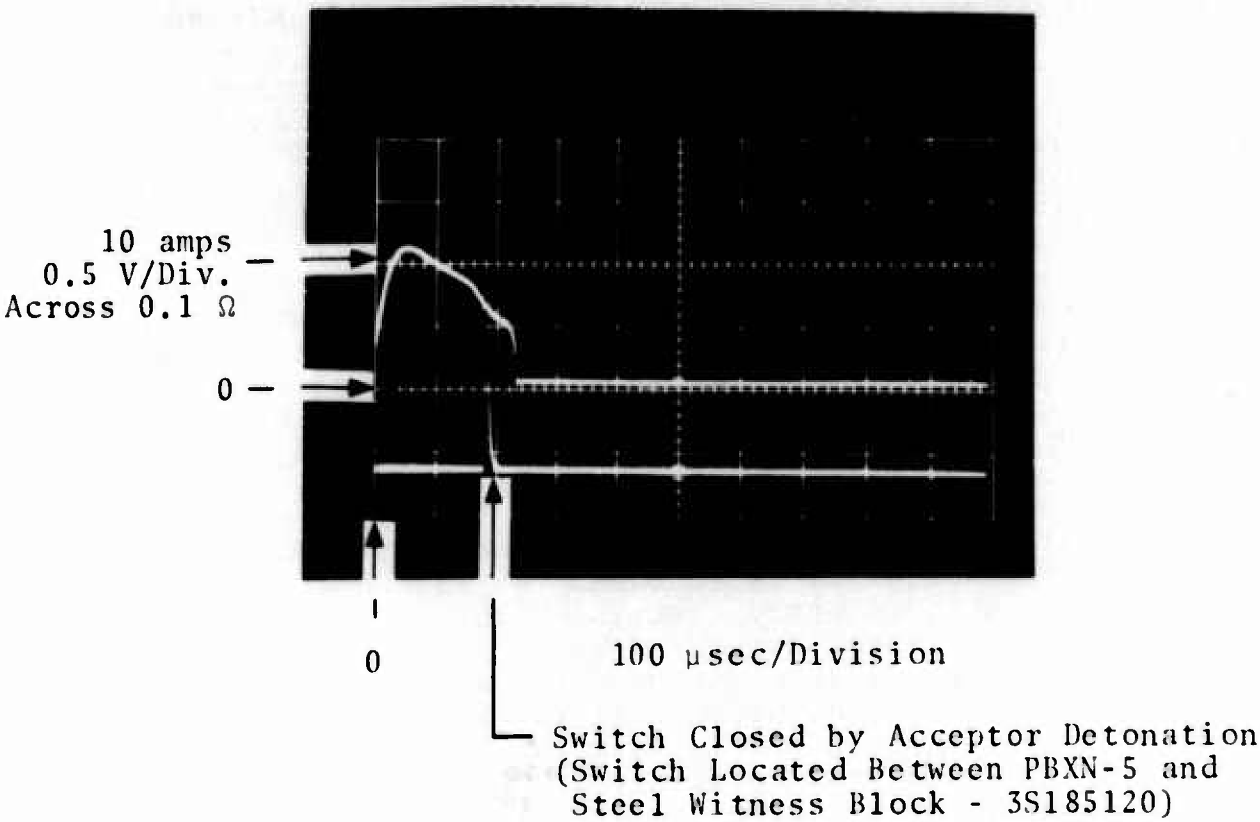


Figure 5. Bridge Wire Current Versus Time and Function Time for Detonation, 3S185100 Mounted per Figure 3, Test No. M-132

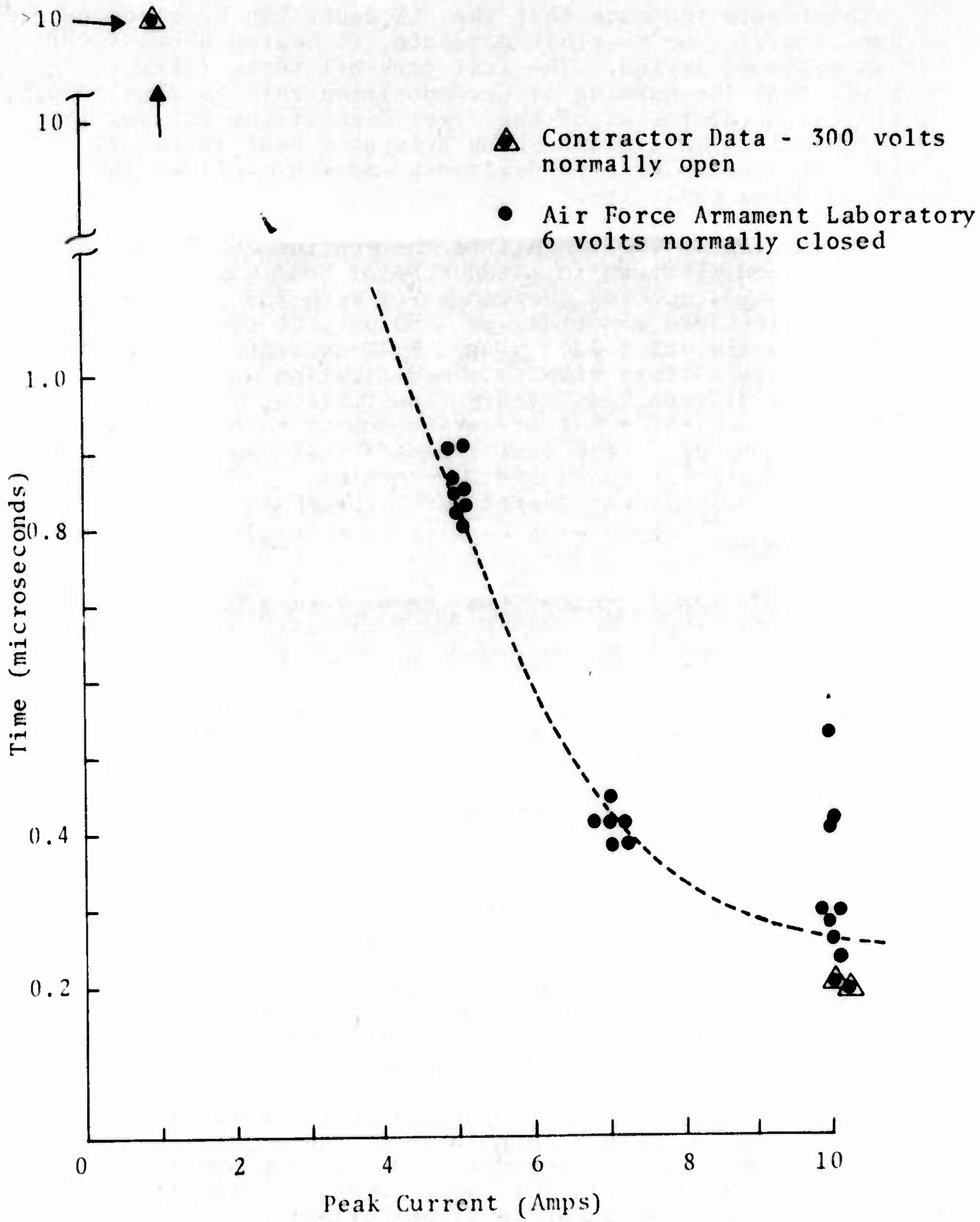


Figure 6. Function Time Versus Maximum Initiation Current from a Constant Voltage Source for Detonation Model 3S185100

These data indicate that the RDX donor can be expected to burn rapidly, or possibly detonate, if heated above 400°F for an extended period. The fast cook-off tests further indicate that the burning or decomposition rate is slow enough to prevent acceleration of the flyer disc if the RDX heating rate is limited by a mount which acts as a heat resistor, giving the cements time to decompose and thus relieve the confined donor explosive.

To supplement the cements as the confinement defeating avenues, a modification to the detonator body was made whereby a fuze plug connected the donor RDX with the outside of the body. The fuze material was a 70 percent cadmium-30 percent tin low-thermal solder with a melting range of 360° to 470°F. Two detonators with this modification were fired successfully at room temperature (see Table I, Tests No. M-110 and No. M-113). The effectiveness of this modification was not pronounced in the fast cook-off tests as reported in Appendix II. The standard model detonator, 3S185100, in its test sleeve 3S185120 was designated "Type P" in the fast cook-off tests, and the fuze plug modified detonator was designated as "Type B."

Four modified detonators in their steel sleeves, Type B, were exposed to the 1800 ±200°F fast cook-off flame. None ruptured its flyer disc. One made an audible report.

Three standard detonators in their steel sleeves, Type P, were exposed to the fast cook-off flame. None ruptured its flyer disc. Two made audible reports. The bare unmodified detonator without its test sleeve made an audible report firing its impactor disc. No acceptor explosive was used in this test.

Following these fast cook-off tests, the second group of 12 detonators was shipped to the Air Force Armament Laboratory for further test evaluation.

<u>Susceptibility to Electromagnetic Radiation</u> - Electromagnetic radiation incident on a detonator and/or its immediate surroundings can manifest itself in any one of several ways in the explosive material contained in the detonator:

Large electric fields can appear in the explosive by inductive coupling with a loop in which the explosive appears as a capacitance in the presence of an electromagnetic pulse (EMP). Also, large fields, in some cases, can result from an internal electromagnetic pulse (IEMP) effect.

The explosive can be subjected to shock stresses as a result of radiation deposition in the explosive itself and/or adjacent materials.

Deposition of radiation in the explosive or surrounding material can cause a rise in the temperature of the explosive.

The bridge wire can be heated by currents which result from inductive coupling of radiation with a loop in which the bridge wire appears as a resistance (EMP).

Thus electromagnetic radiation can result in the application of at least four different kinds of stimuli to the detonator which could conceivably cause initiation of the explosive by, respectively,

- Spark Initiation
- Shock Initiation
- Autoignition (Thermal)
- Hot Wire Initiation.

A. Spark Initiation. The all-secondary explosive detonator discussed here contains no explosive more sensitive than RDX explosive at a density of about 1.6 gm/cm^2. Spark initiation studies at Sandia Corporation[7] have shown that spark initiation of PETN is analogous to exploding bridge wire initiation of PETN. PETN is an explosive which behaves much in the same manner as the less sensitive explosive RDX. Spark initiation of PETN can be realized only if peak power levels approaching one megawatt are realized on sub-microsecond time scales. Stated another way, spark initiation of PETN, and thus RDX, can only be obtained with very specialized circuitry operated in a very specialized way. This discussion thus far has pertained to explosive pressed to a low density $\sim$ 1.0 gm/cm^3. The sensitivity of secondary explosives to any mode of initiation which depends on a shock wave, i.e., exploding wire or spark is reduced very rapidly as the pressing density is increased.

Explosives found in electric detonators, e.g., lead azide and lead styphnate, are usually initiated to detonation whenever a spark breakdown occurs from a static or pulsed field. Lead azide at a typical density of 2.5 gm/cm^3 is initiated with fields in the region of 50 KV/cm or less.

B. Shock Initiation. Under the most ideal conditions, planar front, flat-topped, long duration shock wave, a stress of about 10 kilobars in the explosive is required for initiation of RDX and similar explosives at high pressing density with a maximum run of 5 millimeters.[8] This number, at least 10 kilobars, is to be compared with a shock initiation threshold of about 3.6 kilobars for lead azide.[9] It should be noted that the absorption coefficient and thus the radiation-induced stress will be lower in an organic explosive like RDX than for lead azide or lead styphnate. If the shock wave of interest is generated in a surrounding medium and propagated into the explosive, one should also note that the acoustic impedance of RDX at 1.6 gm/cm^2 is substantially less than PbN_6 at a typical density of 3 gm/cm^3. Thus, for the same absorbed radiation in a surrounding material, the transmitted shock into lead azide will be substantially greater than that transmitted into the RDX.

C. Autoignition (Thermal). When radiation is deposited in a material, the temperature of the material is increased in proportion to the quantity of radiation deposited and the specific heat of the material. The autoignition temperature of RDX is about 230°C while that of PbN_6 is about 335°C. Using specific heats of 0.3 cal/gm/C for RDX and 0.11 cal/gm/C for PbN_6, it is concluded that about 63 cal/gm would be required to initiate RDX while 35 cal/gm would be required to initiate PbN_6. When one notes that the mass absorption coefficient for PbN_6 is one to several orders of magnitude greater than that of RDX in the energy range of interest, it is clear that vulnerability of RDX to initiation by autoignition resulting from radiation deposition in the explosive is of little concern.

D. Hot Wire Ignition. The energy deposited in a detonator bridge wire by an external source necessary to cause initiation is a design parameter which can be varied rather freely by varying the material and size of the bridge wire within the capabilities of the firing circuit. The detonator discussed here offers no inherent safety over conventional detonators requiring similar electrical inputs from hot wire ignition resulting from inductive coupling of electromagnetic energy into a circuit loop external to the detonator. Therefore, usual precautions against electromagnetic pulse coupling should be enforced with this detonator, such as coaxial cables, twisted pairs, non-inductive windings, and shieldings.

SECTION III
CONCLUSIONS

A miniature all-secondary-explosive, low-voltage electric detonator has been developed and demonstrated. Its operating principle is that set forth in the previous program, which demonstrated feasibility. The operating principle required the proper coupling of the following processes:

(1) Hot wire initiation of a self-sustaining deflagration in a donor secondary explosive.

(2) Release and acceleration of a metal impactor disc by confined product gases of the deflagration in the donor explosive.

(3) Shock initiation-to-detonation of an acceptor secondary explosive upon impact by the accelerated impactor disc.

Containing no primary explosive, detonators of this design are as safe to handle and use as are stable secondary explosives in general. The detonator is insensitive to shock and electrostatic charge. The third process listed above can be decoupled from the first two, such that conventional mechanical safeing can be utilized, i.e., the metal impactor disc can be arrested by inert material by either an insert at the end of its gun barrel or by rotation out of alignment with the acceptor explosive. Because of its inherent stability, the requirement for disarm mechanisms is in question.

This reliably demonstrated model utilizes materials which conform to paragraphs 5.2 and 5.3 of MIL-STD-320, is free of nonpermissible couples defined in MIL-STD-889, and the acceptor explosive, PBXN-5, is one of the accepted booster explosives in MIL-STD-1316.

The unit is of a size which will fit within the rotor, with minor modification, of the FMU-1X fuze. The acceptor explosive would then be a part of the booster section.

The power requirement is very small--10 amperes for 200 μsec. Two-hundred microseconds is the function time when the unit is initiated with a current of 10 amperes. Higher currents for shorter periods may produce faster function times and may permit firing from a practical capacitor discharge circuit.

The shelf life should be very good because all materials are compatible and stable.

The detonator with an acceptor explosive of 0.37-inch length repeatedly produces dents of 0.025 inch in a steel block, per Test 301, MIL-STD-331.

The design is safe in fire, as demonstrated in fast cook-off tests, per Naval Weapons Requirements, Warhead Safety Tests, WR-50, 13 February 1964, when the detonator is housed in a case that restricts the heating rate.

Several conditions and parameters are not optimized nor adequately understood to insure successful operation, if engineering modifications are required to adapt to a specific application. These include:

(1) The effect of creep on the confinement of the donor explosive needs further study, although it appears that this pressed RDX powder does stabilize with time under pressure.

(2) The initiator power supply characteristics and their effects on function time should be further understood concurrent with bridge wire changes which would reduce construction difficulty.

(3) The flyer disc velocity repeatability should be determined to permit selection of optimum size components for specified application.

The detonator of the design presented in this report has shown sufficient reliability and performance characteristics to make the all-secondary-explosive, low-voltage, electric detonator a serious contender for application to any munition system, wherein safety in production, storage, handling, and use is an important consideration.

APPENDIX I

CONTRACTOR TEST PROCEDURES

Most of the tests of the detonators of various configurations were performed by contractor personnel at the explosive test facilities of Reynolds Rocket Systems, La Puente, California. The function time tests were made at the contractor-operated, U.S. Government-owned Green Farm Test Site, San Diego, California. The fast cook-off tests were performed by Truesdail Laboratories, Los Angeles, California, whose report is presented as Appendix II.

The instrumentation for the explosive tests is shown in schematic drawing (Figure I-1).

The firing current was calibrated prior to each test series. A dummy resistor, approximately equal to the cold resistance of the platinum bridge wire, was inserted across the detonator terminals in lieu of an actual detonator. An ammeter was placed across the ammeter terminals. The variable resistor was used to establish the desired firing current. After the firing current was established, the ammeter was removed and replaced with a shorting block. The actual detonator leads replaced the dummy load and the test began.

The power/reset switch (S_1) was turned on, applying +12 volts to the SCR. Initiation of the detonator was accomplished by depressing the fire switch (S_2) turning on the SCR, providing a no-bounce current to the detonator, and generating a single sweep synchronization pulse for the oscilloscope.

Actual detonator firing current, as a function of time, was monitored as a developed voltage across a 0.1-ohm resistor. A pin switch containing a small air gap was mounted on the outer surface of the booster charge. Ionization of air in the pin-switch gap, due to booster detonation, caused conduction indicating detonator response time.

Typical firing current and pin-switch waveforms are shown in Figure 5 in the body of the report. The pin-switch channel utilized a reverse polarity display to generate the break in the timing base line. The firing current wave shape reached the peak firing current rapidly and decayed from this maximum as the bridge wire resistance increased under localized temperature effects.

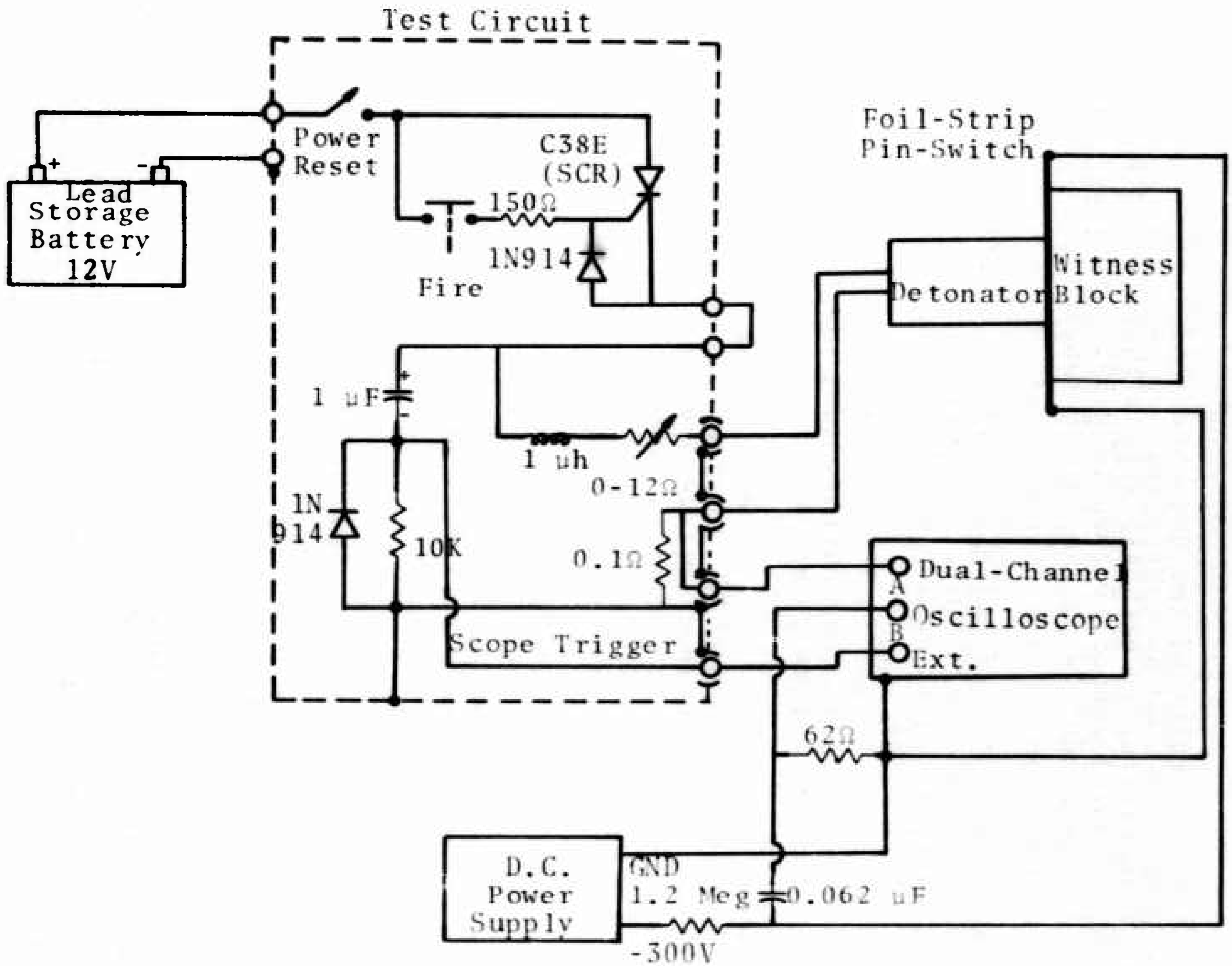


Figure I-1. Detonator Firing and Timing Circuit

APPENDIX II

FAST COOK-OFF TESTS

TRUESDAIL LABORATORIES, INC.

Fast cook-off tests which are set forth in Department of Navy Bureau of Naval Weapons Document WR-50, paragraphs 5.3.2 and 5.3.2.1 were conducted on the Safe Detonator--3S185100 devices.

The work consisted of designing and constructing the testing equipment and performing the tests in accordance with a plan set forth for testing two models of the Safe Detonator.

In order to establish that the testing equipment satisfied the requirements of paragraph 5.3.2.1 of the WR-50, temperature calibration tests were performed.

In order to provide a flame which could continuously envelop the detonator assembly, a forced air-natural gas burner was used. The burner surface area consisted of a series of 0.055-inch-diameter holes measured 0.8 inch by 6.0 inches. The Safe Detonator specimen was supported by a 1-1/4 inch by 1-1/4 inch steel angle. A hole was drilled through the angle which accepted the bolt of the detonator. The hole through the angle was counterbored so that the bolt could not be tightened against the angle. This arrangement permitted the detonator to be loosely supported by the angle. The detonator mounting angle was attached to an aluminum plate by two 10-32 screws. The aluminum plate was 1 inch thick and the detonator mounting angle was attached to the edge. Between the angle and the edge of the plate, asbestos concrete washers were used so as to provide a space of 1/2 inch between the angle and the aluminum plate.

The initial test to determine the flame and detonator specimen temperature was conducted with the angle bolted directly to the aluminum plate. Using this procedure, it was determined that the aluminum plate provided a larger heat sink than possibly existed during the production mounting of the detonator assembly. The results of the thermal tests involving these two configurations will be discussed later in the report.

The gas burner and the detonator assembly support structure were contained in a section of steel pipe 12-inch I.D. by 3/8-inch wall thickness. The section of pipe was 18 inches long. The pipe was set on end. Over the top of the pipe was placed a piece of expanded metal steel which was 1/8 inch thick.

In order to determine the flame temperature, chrome alumel thermocouples, whose output was connected to a Minneapolis Honeywell chart recorder, were positioned in the nonoxidizing portion of the flame. The range of the recorder was 1,000°F to 2,600°F. Before tests were started, the instrument was calibrated against a millivolt standard. All tests were conducted in the section of pipe previously described. The temperature of the flame was established by probing the flame area with a thermocouple in the vicinity of the detonator specimen. It was found that by controlling the flow of air and gas, the enveloping flame could be easily maintained at a temperature between the specified range (1,800°F ± 200°F). Once the air and gas flow had been set, the flame temperature could be maintained over a range of 50°F.

In order to determine the rate of increase in temperature of the specimen when subjected to an enveloping flame of approximately 1,800°F, a thermocouple was installed in the explosive chamber of a detonator assembly. This unit did not contain the explosive charge. Tests were conducted with the mounting angle bolted directly to the aluminum plate and with the mounting angle separated from the aluminum plate by a space 3/4 inches. With the angle bolted directly to the aluminum plate, sufficient heat was conducted from it so that the angle never attained the same color red that the detonator unit attained. With the angle separated from the aluminum plate by 1/2 inch, the detonator mounting angle obtained approximately the same color red as did the detonator assembly. Graph No. 1 (Figure II-1) depicts the temperature rise characteristics of the two detonator mounting arrangements.

Four of the detonator assemblies were not colored and for the purpose of this report are identified as detonator assembly P. Additionally, four units were furnished in which the detonator body was painted with blue dye. For the purpose of this report, they are identified model B. The prescribed test procedure was to first test the "P" units in accordance with paragraph 5.3.2.1 of the WR-50. These units were to be tested until all four units successfully passed the 15-minute test or until the first of the four units exploded. If the four units successfully passed the test, the "B" units were not to be tested. If a "P" unit exploded, no further "P" units were to be tested and the next unit to be tested was the "B" configuration. In this procedure the "B" units would be tested until all four units successfully passed the test or until a "B" unit exploded. If a "B" unit exploded, the test was to be stopped.

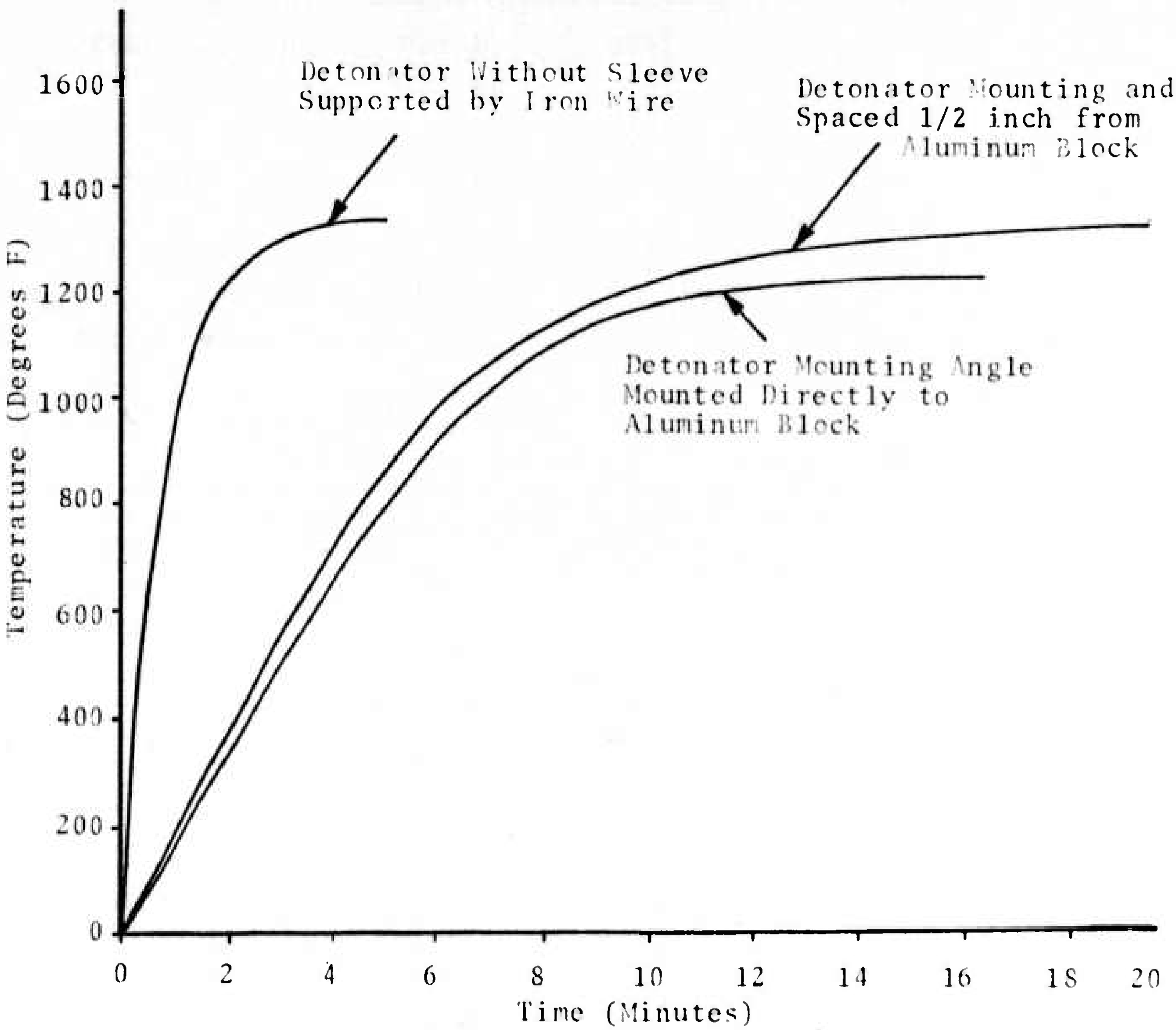


Figure II-1. Detonator Temperature Versus Time

The following table gives the results of the tests:

Detonator Specimen Type	Detonator Specimen Number	Mean Flame Temperature (Degrees F)	Duration of Test (Minutes)	Remarks
P	1	1850	1.645	Unit exploded*
B	1	1675	15	Survived
B	2	1960	15	Survived
B	3	1725	1.65	Unit exploded*

The witness block which was attached to units P-1 and B-3 showed evidence of the explosion although the steel did not appear to be deformed. The witness block of units B-2 and B-3 contained some carbonized material from the detonator device.

Subsequent to the above described tests, it was decided that the three P units and the one B unit which had not been tested should be tested. The test equipment previously described was again set up and the temperature-measuring instrumentation recalibrated. These units were then tested in accordance with the procedure previously described. The results of the tests are tabulated below:

Detonator Specimen Type	Detonator Specimen Number	Mean Flame Temperature (Degrees F)	Duration of Test (Minutes)	Remarks
B	4	1925	15	Survived
P	2	1950	15	Survived
P	3	1775	1.8	Unit exploded*
P	3	1775	15	Continued test after explosion until end of 15 minute period
P	4	2000	0.2	Detonator** tested without sleeve. Unit exploded beneath sleeve.

After the tests were performed, a bare detonator body which contained no explosive charge was used for the

---

*For footnotes, see page 41.

purpose of determining the temperature-time relationship when the unit was placed in the same flame as used to test the detonator. To perform this test an Iron-Constantan thermocouple was installed in the body where the explosive charge is normally held. The flame temperature was monitored and maintained at a mean temperature of 1850°F. The temperature-time characteristics for this device are plotted on Figure II-1.

Footnotes by E. A. Day of Contractor

*Upon disassembly of the units, the flyer discs were intact. The epoxy cement used to hold the initiation lead to the header and the header were destroyed; the fuze plug was gone from the "B" unit. This indicates that the RDX burned rapidly but failed to develop sufficient pressure to punch out the flyer section of the aluminum alloy disc.

**Detonator designated P-4 was exposed to the gas flame directly. The sleeve and retainer screw, Part Nos. 3S185212 and 3S185122 were not used. At twelve seconds, the decomposing RDX developed enough pressure to punch out the aluminum flyer disc which impacted a steel witness block at the end of the barrel. The RDX pressure was sufficient to split the detonator case, Part No. 3S185101.

APPENDIX III
AIR FORCE TESTING OF CONTRACTOR DETONATOR

Twenty-four prototype detonators furnished by the contractor were function tested in the Explosive Dynamics Laboratory, AFATL. The procedures and results were as outlined below:

1. To insure compaction of the RDX donor charge, each detonator cap was tightened to 60 inch-pounds prior to firing. The firing circuit for the test was patterned after that used by the contractor. A No. 4 pencil lead was placed at the base of the detonator to function as a switch. A six-volt battery was used to establish a potential across this switch. To back up data on this technique, an aluminum foil switch was placed across the bottom of the detonator with a 180 VDC potential. Both switches were monitored with Tektronic model 555 oscilloscopes with type K vertical amplifiers. Function time was measured as the time difference between application of firing voltage (trigger) and breakout of the acceptor charge which broke the foil and lead switches. Type 21A and 22A time base units were incorporated using ranges of 0.1 ms/cm and 0.5 ms/cm. Other instrumentation consisted of a steel witness block to measure detonator output.

2. Of the 24 detonators tested, six malfunctions occurred. These malfunctions were due to:

a. Trigger malfunction.

b. Insecure placement of detonator on witness plate.

c. Pre-ignition due to a current leakage through the oscilloscope grounding.

In the final three shots, the detonators that experienced pre-ignition were examined. The leads had apparently shorted to the detonator housing. When voltage was applied to the aluminum foil switch, a current was established in the bridgewire. This caused pre-ignition. Table III-1 gives the test results from each detonator.

TABLE III-1. TEST RESULTS FOR AIR FORCE TESTING OF DETONATOR

Shot No.	Firing Current (AMPS)	Function Time A (1)	Function Time B (2)	Dent Depth (Inch)	Scope Deflect	Remarks
			SERIES No. 1			
1	5A	0.85 ms	-	0.026	4.1V	Go
2	5A	0.9 ms	-	0.023	4.1V	Go
3	5A	-	-	0.028	-	Trigger malfunction
4	5A	0.82 ms	-	0.025	4.1V	Go
5	5A	0.84 ms	-	0.026	4.1V	Go
6	5A	0.86 ms	-	0.029	4.1V	Go
7	5A	0.82 ms	-	0.026	4.1V	Go
8	5A	0.81 ms	-	0.023	4.1V	Go
9	5A	0.9 ms	-	0.031	4.1V	Go
10	7A	0.38 ms	-	0.028	4.1V	Go
11	7A	0.41 ms	-	0.009	4.1V	Detonator not secure to plate
12	7A	0.41 ms	-	0.025	4.1V	Go
			SERIES No. 2			
1	7A	0.41 ms	-	0.027	4V	Go
2	7A	-	-	0.026	-	Trigger malfunction
3	7A	0.38 ms	-	0.0275	4V	Go
4	10A	0.28 ms	-	0.028	4V	Go
5	10A	0.41 ms	-	0.0295	4V	Late
6	10A	0.27 ms	-	0.028	4V	Go
7	10A	0.52 ms	-	0.028	4V	Late
8	10A	0.23 ms (3)	0.23 ms	0.021	4V	Go
9	10A	0.24 ms	0.24 ms	0.024	4V	Go
10	10A	-	-	0.021	-	Pre-ignition

TABLE III-1. (concluded)

Shot No.	Firing Current (AMPS)	Function Time A (1)	Function Time B (2)	Dent Depth (Inch)	Scope Deflect	Remarks
11	10A	-	-	0.020	-	Pre-ignition
12	10A	-	-	0.021	-	Pre-ignition

NOTE: (1) Function time A was recorded making use of a pencil lead switch.

(2) Function time B was recorded making use of an aluminum foil switch.

(3) Both switches displayed a difference in function time of only a few microseconds.

REFERENCES

1. V. F. Lemley, P. B. Ritter, G. E. Seay and M. H. Purdy, "Feasibility of an All-Secondary-Explosive, Low-Voltage, Electric Detonator," Air Force Armament Laboratory Report AFATL-TR-71-148, November 1971.

2. N. Griffiths, H. Rowson, T. H. Quarry, "The Development of a Secondary Explosive Detonator," Armament Research and Development Establishment Memorandum (MX) 34/61, July 1961.

3. R. J. Reithel, "The Hot Wire Ignition of Secondary Explosive," Los Alamos Scientific Laboratory Report LA-3668.

4. J. Roth and B. O. Reese, "Plane-Wave Shock Sensitivity of PBX 9404," Stanford Research Institute, Final Report Project PUG-7571, June 18, 1969.

5. J. Roth and J. H. Blackburn, "Effect of Initial Temperature on the Shock Sensitivity of Granular Explosives," Stanford Research Institute, First Annual Report Contract 58-1348, August 28, 1967.

6. Engineering Design Handbook, Explosives Series, Properties of Explosives of Military Interest, Army Materiel Command Pamphlet AMCP 706-177, March 1967, p. 69.

7. D. L. Allensworth and T. J. Tucker, "A Feasibility Study on the Utilization of Pulse Transformer-Spark Detonator Firing Sets in Ordnance Applications," Sandia Laboratories Report SC-DR-71-0916, April 1972.

8. I. E. Lindstrom, "Planar Shock Initiation of Porous Tetryl," JAP II, 337, January 1970.

9. J. H. Shea, A. Mazella, L. Aurami and H. J. Jackson, "Effects of a Radiation Pulse Upon a Primary Explosive (U)," Picatinny Arsenal Technical Report 4230, May 1971.

(The reverse of this page is blank.)

INITIAL DISTRIBUTION

AFSC/DLW	2
AFSC/SDWM	1
AFSC/DPSL TECH LIB	1
Hq USAF/RDPA	1
ASD/ENYS	1
FTD/PDYF	1
AFML/LNP	1
AFML/LPH	1
AFML/LL	1
AFIT/ENB	1
Def Nucl Agt/APTL	1
CIA CRS/ADD/PUB	2
CIA/MRS SILVIA	1
DOD Expl Safety Bd	1
AEC/Div of Hq Serv, Libr Br G-049	1
AFOSR/NAE	1
AU AUL/LSE-70-239	1
3249 Tech Tng Sqd	1
USA Matl Comd/AMCRD-WB	1
Dir Tech Info Adv Rsch Proj Agcy	1
Off Asst Dir/DDR&E/Engr Tech	1
Def Intel Agcy/DI-6E1	1
Naval Ammun Depot/Code 501-A3	1
USA MUCOM Op Rsch Grp	1
Edgewood Ars/SMUEA-DE-MA	1
Edgewood Ars/SMUEA-DE-M	3
Tech Sup Direct/SMUEA-TS-T	1
Aberdeen/Ch, Tech Libr	1
USNWC/Code 603	1
USNWC/Code 456	2
USNWC/Code 753	2
USA ARDC Ball Rsch Labs/AMXRD-BTL	1
USA Test & Eval Comd/AMSPE-NB	1
Dir, Ball Rsch Lab/AMXRD-BD	2
PicatinnyArs/SMUPA-ET/Dr. Slagg	1
PicatinnyArs/SMUPA-FR-L	1
Picatinny Ars/SMUPA-FR-E/Dr Walker	2
PicatinnyArs/SMUPA-AD-D-W	1
PicatinnyArs/SMUPA-FR/L.H.Eriksen	1
USA MUCOM/AMSMU-RE-R/J.Turteltaub	1
Frankford Ars/SMUFA-L5000/Dr.McNeill	1
USN Wpns Lab/GB & GW	2
USN Wpns Lab/GWL	1
USN Wpns Lab/Code GC	1
Redstone Sci Info Ctr/Ch Doc Sec	2
US Army Wpns Cmd/SWERR-W	1
CNO/OP982E4	1
Nav Air Sys Cmd/Code AIR 5323	2

NavOrdSys Cmd/Code ORD-035D	1
USNRL/Code 7780	2
Nav Underwater Sys Ctr/Code LA151	2
Nav Wpns Sta/Code 50	3
USN Ord Sta/Tech Lib	2
Det 63/OOAMA/MMNEI	1
USN Civil Engr Lab/Code L31	1
USA Rsch Off/CRD-AA-IP	1
USNOL/Code 022	2
Nav Ord Lab/Code 233	2
DDC	2
Nav Wpns Eval Fac/Code WE	1
Hq USMC/Code AAW	1
Hq USMC/Code AO3H	4
Mar Corps Ln Off, USA Avn Ctr	1
USAF Rep/Snow Hall,USA Fld Art Sch	1
USA Matl 7 Mech Rsch Ctr/AMXMR-STL	2
AFATL/DL	1
AFATL/DLOSL	2
AFATL/DLIP	1
AFATL/DLIF	1
AFATL/DLIW	5
AFATL/DLOU	1
ADTC/WE	1
USAFTAWC/DT	1
USAFTAWC/TEYM	1
USAFTAWC/CB	2
USAFSOF/DOR	2
USAFSOF/DM	2
AFATL/DLR	1
AFATL/DLX	1
AFATL/DLY	1
AFATL/DLG	1
TRADOC/ADTC/DO	1

(The reverse of this page is blank.)

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Systems, Science and Software P. O. Box 1620 La Jolla, California 92037	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

DEVELOPMENT OF A MINIATURE ALL-SECONDARY-EXPLOSIVE, LOW-VOLTAGE, ELECTRIC DETONATOR

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report - 9 May 1972 to 30 January 1973

5. AUTHOR(S) (First name, middle initial, last name)

E. A. Day
P. B. Ritter
G. E. Seay

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1973	51	9

8a. CONTRACT OR GRANT NO. F08635-72-C-0165 b. PROJECT NO. 2511 c. Task No. 01 d. Work Unit NO. 006	9a. ORIGINATOR'S REPORT NUMBER(S) SSS-R-73-1514 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFATL-TR-73-40

10. DISTRIBUTION STATEMENT

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied February 1973 . Other requests for this document must be referred to the Air Force Armament Laboratory (DLIW), Eglin Air Force Base, Florida 32542.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Available in DDC	Air Force Armament Laboratory Air Force Systems Command Eglin Air Force Base, Florida 32542

13. ABSTRACT

An operationally reliable miniature version of an all-secondary-explosive, low-voltage electric detonator has been developed and produced in test quantities. This safe detonator is based on the design which earlier was proven feasible. The detonator consists essentially of a donor explosive combustion chamber, an impactor disc, an airgap, and an acceptor explosive column which provides for proper coupling of the following three critical processes: (1) Hot-wire initiation of a self-sustaining deflagration in a donor secondary explosive. (2) Release and acceleration of a metal impactor disc by confined product gases of the deflagration in the donor secondary explosive. (3) Shock initiation-to-detonation of an acceptor secondary explosive upon impact by the accelerated impactor disc. It was found that the third process was mechanically separable from the first two. By separating it, detonator size can be reduced so that the first and second processes can be fitted to the FMU-1X fuze rotor while the third process can become part of the booster. The design parameters which control the critical process are discussed. A static fix of the assembly to make the detonator safe in a fast cook-off situation was demonstrated. Sensitivity to electromagnetic radiation loading is discussed. Prototype detonators furnished under this program were function tested by the Armament Laboratory. The results of these tests are included in Appendix III.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Low-Voltage Electric Detonator All-Secondary-Explosive Electric Detonator FMU-1X Impact, Short Delay Fuze System Short Delay Fuze System Miniaturized Low-Voltage Electric Detonator						

UNCLASSIFIED
Security Classification